

A TOE–NRBV Integrated Framework for Inclusive Blue Economy Development: Enhancing Supply Chain Sustainability and Small-Scale Fishers' Livelihood Resilience in Southern Coastal Malang, Indonesia

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Abstract

Despite growing interest in Blue Economy policy, empirical studies that integrate TOE and NRBV perspectives to explain how technological, organizational, regulatory, and natural-resource factors jointly shape supply-chain sustainability and small-scale fishers' livelihood resilience, particularly in Indonesian coastal communities, remain scarce. This study develops and tests an integrated Technology–Organization–Environment (TOE) and Natural Resource-Based View (NRBV) framework to design an inclusive Blue Economy model in the southern coastal region of Malang, Indonesia. Using Structural Equation Modeling (SEM) on survey data from 150 small-scale fishing households across Sendangbiru, Tambakrejo, and Sitiarjo, the research investigates the interplay between technological adoption, organizational capacity, regulatory support, supply chain risk, cost perception, and environmental awareness. Findings indicate that the six factors significantly enhance both Blue Economy investment and livelihood resilience, which in turn drive sustainable supply chain performance. Livelihood resilience exerts the strongest influence, highlighting the critical role of social capital, adaptive capacity, and resource sustainability in shaping inclusive development. The integrated TOE–NRBV model provides a robust analytical and practical framework for strengthening small-scale fisheries within global sustainability transitions.

Keywords

Blue economy; Supply chain sustainability; Livelihood resilience; Small-scale fisheries; TOE framework; NRBV; Inclusive development

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Introduction

Indonesia, the world's largest archipelagic state, has positioned marine development as a strategic pillar in its national economic transformation. The Blue Economy concept has been adopted as a development approach to harmonize economic growth, social welfare, and marine ecosystem sustainability (Evans *et al.*, 2023; Muhammed Fazil, 2025; Paruĝ, Jabbr and Lazrag, 2024). This commitment appears in national development agendas, including the Long-Term National Development Plan (RPJPN) 2025–2045, which explicitly emphasizes the principles of “inclusive and sustainable” development to ensure that the benefits are equitably shared across all layers of society, particularly within coastal communities. The fisheries sector, dominated by more than 90% small-scale fishers, represents both the backbone of Blue Economy implementation and the frontline in safeguarding national food security (Bennett *et al.*, 2021; Stacey *et al.*, 2021).

The Southern Coastal Area of Malang, with its shoreline facing directly onto the Indian Ocean, serves as one of the strategic capture fisheries hubs in East Java and plays a critical role in implementing Blue Economy policies. The fisheries sector contributed significantly, accounting for 14.60% of Malang Regency's Gross Regional Domestic Product (GRDP) in 2023. However, this potential is accompanied by constraints that threaten both sustainability and inclusiveness. Sectoral growth has slowed from 3.39% in 2022 to 2.63% in 2023, suggesting persistent structural constraints that local policy implementation has yet to address.

Global dynamics in marine resource governance increasingly influence local development trajectories. Intensifying competition in international markets compels the fisheries sector to adapt to quality standards, sustainability certifications, and production efficiency. This poses particular challenges for small-scale fishers, who largely rely on traditional technologies and face limited access to market information. Without adequate policy interventions, capacity gaps between small- and large-scale actors are likely to widen. Thus, integrating local policies with global standards is essential to ensure that marine-based development is not merely focused on economic output but also on social and environmental sustainability.

Digital transformation offers pathways to strengthen supply chain transparency and inclusiveness. Access to real-time market prices, weather data, and digital marketing tools can enhance fishers' bargaining power. However, technological adoption remains low due to digital illiteracy, inadequate coastal internet infrastructure, and high upfront investment costs. As such, capacity building and community empowerment must be integral components of Blue Economy development, ensuring that small-scale fishers become active agents of adaptation and innovation rather than passive recipients of policy interventions.

A key challenge lies in structural inequalities masked by average welfare indicators. A study (Husni *et al.*, 2022) on the Fishermen's Exchange Rate (NTN) in East Lombok revealed sharp disparities and market price uncertainties, showing that small-scale fishers, the majority group, remain highly vulnerable, operating just above the breakeven point and being extremely sensitive to economic and environmental shocks (Freduah,

Fidelman and Smith, 2019). Fishers face complex challenges, ranging from fluctuating catches, climate change impacts, limited access to technology and capital, to weak bargaining power within supply chains (Kinseng, 2021; Zhao *et al.*, 2025). These conditions create a gap between macro-level Blue Economy objectives and the micro-level needs of its primary actors (strengthening fair and resilient livelihoods). On one hand, sustainable supply chain performance is influenced by factors from the Technology–Organization–Environment (TOE) framework as well as the Natural Resource-Based View (NRBV) (Andersén, 2021; Satyro *et al.*, 2024). On the other hand, livelihood resilience is built upon fishers’ buffering capacity, organizational ability, and learning capacity (Matter, Boillat and Speranza, 2021). Failure to bridge these two dimensions would lead to exclusive and unsustainable development. Given this empirical and conceptual gap, the research question of this study is: *How can an inclusive Blue Economy model be designed for the Southern Coastal Area of Malang that simultaneously enhances sustainable supply chain performance and the livelihood resilience of small-scale fishers?*

Theoretical Framework

This study is anchored in two complementary theoretical perspectives: the Technology–Organization–Environment (TOE) framework and the Natural Resource-Based View (NRBV) (Figure 1).

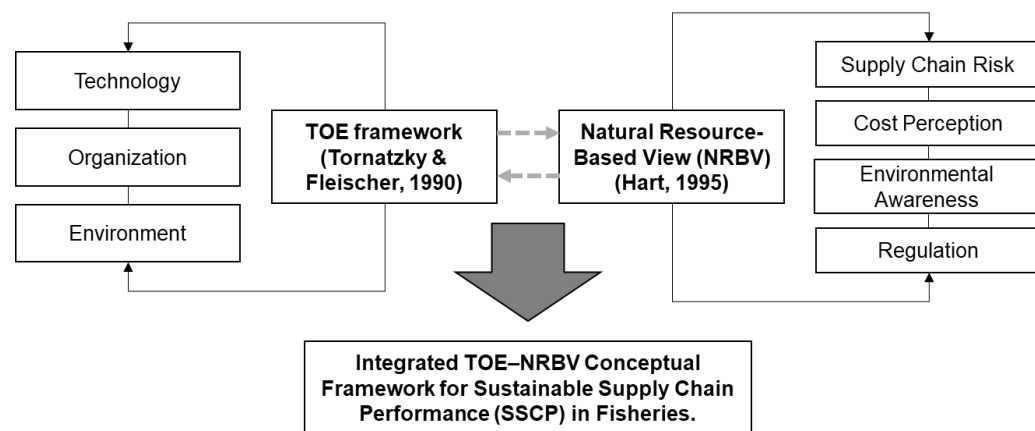


Figure 1: Research Model

The TOE framework (Tornatzky and Fleischer, 1990) provides a holistic explanation of how organizations adopt and implement innovations based on three main contexts: (1) Technology, which relates to the availability and suitability of technological resources to support efficiency and innovation; (2) Organization, which includes internal resources such as managerial capacity, communication, leadership, and decision-making structures; and (3) Environment, which encompasses external pressures and supports, such as regulations, market dynamics, and industry characteristics. Within the fisheries sector, TOE helps explain how technological adoption, organizational governance, and regulatory frameworks influence the sustainability of supply chain performance.

The Natural Resource-Based View (NRBV) (Hart, 1995) extends the resource-based theory by emphasizing that a firm’s or community’s long-term competitive advantage is

closely linked to its ability to integrate environmental stewardship. NRBV highlights strategic capabilities such as environmental awareness, cost perception, and sustainable development, all of which require proactive environmental management. In the context of small-scale fisheries, NRBV explains how environmental awareness, perception, supply chain risk, and blue economy investment contribute to both blue economy innovation and livelihood resilience.

Integrating these two perspectives, this study develops a conceptual model where Technology, Organization, and Environment represent the TOE dimensions, while risk in supply chain, cost perception, environmental awareness, blue economy investment, and livelihood resilience are rooted in NRBV. Together, these constructs are hypothesized to influence sustainable supply chain performance (SSCP) in fisheries. This integrated framework allows for a comprehensive analysis of both internal and external factors that shape the inclusiveness and sustainability of the blue economy in coastal Malang, Indonesia.

Methodology

Description of the study area

The study was conducted in the southern coastal region of Malang Regency, East Java Province, Indonesia (Figure 2). This coastal area stretches approximately 102 km along the Indian Ocean, and encompasses several fishing communities such as Sendangbiru, Tambakrejo, and Sitarjo. The region is characterized by a diverse coastal geomorphology, including sandy beaches, rocky shores, estuaries, and small islands such as Sempu Island, which functions as both an ecological buffer and a traditional fishing ground. The marine waters of this area are highly productive due to the influence of the Indian Ocean currents, making it one of the most important capture fisheries centers in East Java.

Administratively, the southern coast of Malang is part of the regency's development zone for marine and fisheries, and its coastal communities are predominantly engaged in small-scale capture fisheries. More than 80% of households depend directly on fishing and related activities for their livelihoods. Fishing operations are mostly carried out using small boats (≤ 10 GT) with traditional gear such as hand lines and traditional nets. Despite its potential, the area is prone to challenges such as seasonal variability of fish catch, exposure to high-energy waves from the Indian Ocean, and limited infrastructure for fish processing and cold storage. These factors have shaped the socio-economic dynamics of the communities, making them highly dependent on both natural resource sustainability and policy interventions in the fisheries sector.

Sampling methods

The population of the study area comprised small-scale fishing households located in the southern coastal region of Malang Regency, East Java, Indonesia. A multistage sampling procedure was used to collect primary data for the Structural Equation Modeling (SEM) analysis (Khan *et al.*, 2022). Firstly, three coastal villages with active landing sites: Sendangbiru, Tambakrejo, and Sitarjo, were purposively selected based on fishing

intensity and community engagement in the fisheries value chain. Secondly, from each village, fishing households were randomly selected from the official list of local fishermen provided by the Fisheries Office. To ensure transparency in sampling proportionality, the number of respondents selected from each village was determined based on the proportion of registered fishing households in the respective village relative to the total population of fishing households across all three villages. Accordingly, a total of 150 respondents were distributed proportionally across the villages following their respective population shares.

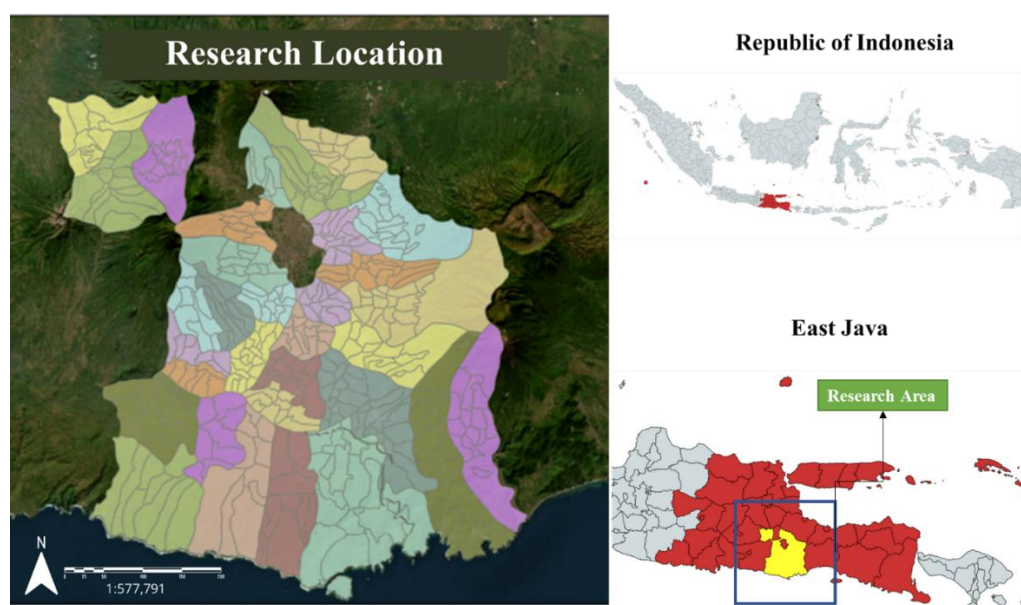


Figure 2: Location of the study area

Sampling proportions accounted for household size and activity level to ensure representativeness across diverse fishing operations. Respondents included both male and female members of fishing households who directly participate in or support fishing and post-harvest activities. The survey was conducted from July to September 2025, coinciding with the peak fishing season in the southern Indian Ocean. The sample size of 150 was determined to satisfy the minimum requirements for SEM analysis, which generally recommends 5–10 observations per estimated parameter. This approach ensured that the data collected were both statistically adequate and contextually representative of small-scale fishers in the study area.

Research tools

Multiple research tools were used to ensure comprehensive and triangulated data collection from the fishing communities in the southern coastal region of Malang Regency, East Java. A semi-structured questionnaire was administered through face-to-face interviews with the 150 selected respondents. The questionnaire covered household socio-demographics, fishing assets, livelihood strategies, income variability, market access, and adaptation to environmental changes. This approach ensured that both

quantitative and qualitative dimensions of small-scale fisheries could be captured for further Structural Equation Modeling (SEM) analysis.

In addition, five focus group discussions (FGDs) were organized with male and female fishers as well as fish processors at commonly used community meeting points. A total of 30 participants were randomly chosen for the FGD sessions, with 6 participants in each group, representing different age groups and roles in the fisheries value chain. Key questions were asked in line with the study objectives, such as livelihood vulnerability, market constraints, climate variability, and coping strategies. This participatory approach helped reduce personal bias and validate shared experiences within the community. Furthermore, four key informant interviews (KIIs) were conducted with local leaders, fisheries extension officers, and fish traders to gather insights on institutional arrangements, supply chain dynamics, and policy implementation. After data collection, all responses were coded and tabulated using Microsoft Excel 2019. Statistical analyses were performed with SPSS version 26 to generate descriptive statistics, correlation measures, and factor loadings required for SEM. Data cleaning and validation were carefully undertaken to enhance accuracy and reliability. The Research Flow can be seen in figure 3:

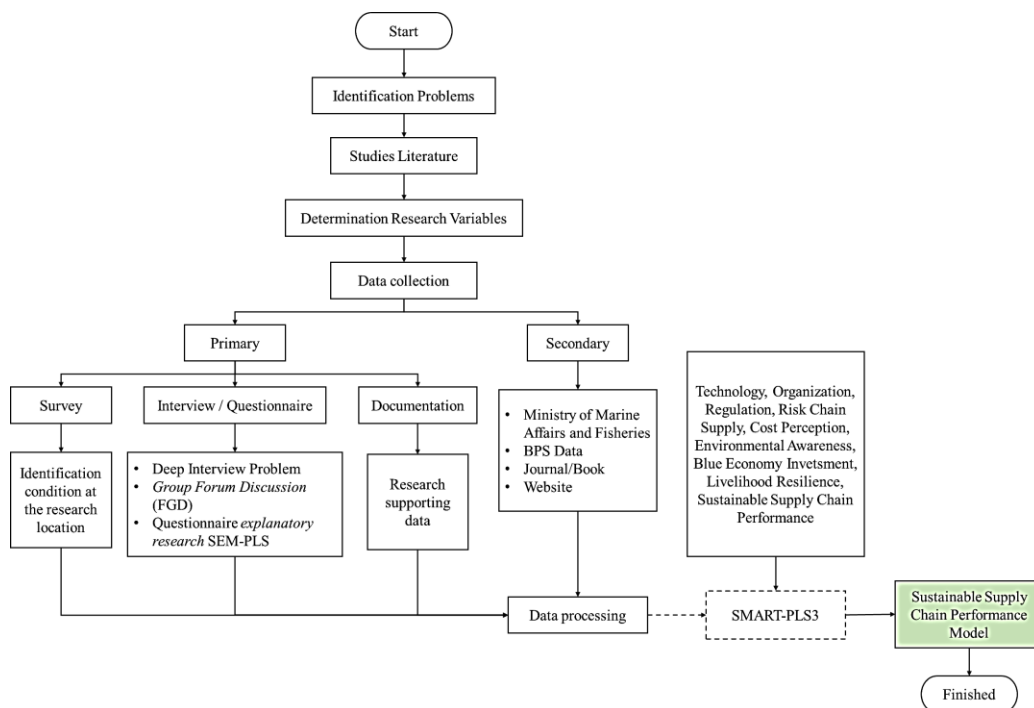


Figure 3: Research Flow

Measurement of major indicators

Measurement of major indicators was based on nine key variables identified from the literature and adapted to the fisheries context in the southern coastal region of Malang Regency (Table 1). Technology was measured by assessing use of information technology, access to modern fishing equipment, adoption of eco-friendly tools,

efficiency improvement through technology, and the level of digital innovation adoption. Organization was evaluated by indicators of leadership, participatory decision-making, effectiveness of internal communication, resource management capacity, and an innovation-supportive culture within fishing groups or cooperatives. Regulation was measured through the clarity of government rules, implementation of marine policies, compliance with environmental regulations, availability of fiscal incentives, and legal protection for small-scale fishers.

Table 1: Research Variable (Andersén, 2021; Appannan *et al.*, 2023; Hart, 1995; Satyro *et al.*, 2024; Tornatzky and Fleischer, 1990)

No.	Variable	Definition	Indicators
1.	Technology	The ability to use and apply technology to support sustainable supply chains in the fisheries sector.	1. Use of information technology 2. Access to modern equipment 3. Utilization of eco-friendly technology 4. Production efficiency through technology 5. Level of digital innovation adoption
2.	Organization	Structures, management, and coordination within organizations that influence investment decisions and supply chain efficiency.	1. Organizational leadership 2. Participatory decision-making 3. Effectiveness of internal communication 4. Resource management capacity 5. Innovation-supportive organizational culture
3.	Regulation	Policies, rules, and laws governing blue economy activities and sustainable supply chains.	1. Clarity of government regulations 2. Implementation of marine policies 3. Compliance with environmental regulations 4. Fiscal incentive support 5. Legal protection for business actors
4.	Supply Chain Risk	The likelihood of disruptions or uncertainties within the supply chain system from upstream to downstream.	1. Dependence on raw materials 2. Market price fluctuations 3. Distribution and logistics disruptions 4. Weather and natural uncertainties 5. Technological or operational risks
5.	Cost Perception	Stakeholders' perspectives on expenses incurred in	1. Initial investment costs 2. Perceived ROI from green technologies 3. Maintenance costs of new

No.	Variable	Definition	Indicators
		implementing sustainable practices.	systems 4. Affordability of infrastructure 5. Burden of long-term operational costs
6.	Environmental Awareness	The degree of concern of individuals or organizations toward the environmental impacts of economic activities.	1. Knowledge of environmental issues 2. Commitment to ecosystem preservation 3. Waste reduction practices 4. Support for conservation programs 5. Emission reduction initiatives
7.	Blue Economy Investment	Allocation of financial resources into the marine sector that supports sustainable growth.	1. Capital commitment to marine enterprises 2. Diversification of funding sources 3. Use of environmentally based financing 4. Investment in port infrastructure 5. Participation in public-private partnerships
8.	Livelihood Resilience	The ability of coastal households or communities to sustain income and long-term well-being.	1. Diversification of income sources 2. Access to productive assets 3. Social and institutional networks 4. Coping capacity during crises 5. Sustainability of natural resources
9.	Sustainable Supply Chain Performance (SSCP)	The effectiveness of systems from production to distribution that integrate economic, social, and environmental efficiency.	1. Logistics and distribution efficiency 2. Sustainable input sourcing 3. Value addition in fisheries products 4. Stakeholder involvement in decision-making 5. Compliance with sustainability standards

Supply chain risk was measured by dependence on raw materials, exposure to price fluctuations, vulnerability to logistic disruptions, weather uncertainty, and operational or technological risks. Cost perception was assessed through indicators such as perceived affordability of initial investment, expected return on investment (ROI) from green technologies, maintenance costs, accessibility of infrastructure, and the burden of long-term operational expenses. Environmental awareness was measured by fishers' knowledge of ecological issues, commitment to ecosystem preservation, waste reduction

practices, support for conservation programs, and initiatives to reduce emissions. Furthermore, blue economy investment was evaluated based on the commitment of capital toward marine enterprises, diversification of funding sources, use of environmentally oriented financing, investment in port or landing site infrastructure, and participation in public–private partnerships. Livelihood resilience was measured through diversification of income sources, access to productive assets, social and institutional networks, coping capacity during crises, and the sustainability of natural resources. Finally, sustainable supply chain performance (SSCP) was assessed by evaluating logistic and distribution efficiency, sustainable input sourcing, value addition in fisheries products, stakeholder involvement in decision-making, and compliance with sustainability standards.

To ensure measurement credibility and reduce common method bias, all indicators were measured using a structured questionnaire with five-point Likert scales ranging from “strongly disagree” to “strongly agree.” Common method bias was examined using Harman’s single-factor test, which confirmed that no single factor dominated the variance, and multicollinearity was assessed through Variance Inflation Factor (VIF) values, all of which were below the acceptable threshold. Additionally, qualitative insights from focus group discussions (FGDs) and key informant interviews (KIIs) were used for triangulation.

Results

Outer Loading

Outer loading is a statistical measure indicating the strength of association that indicates how strong the correlation is between an indicator (an observed variable, such as a question item in a questionnaire) and a latent variable (a construct that cannot be measured directly). Simply put, outer loading measures the validity or accuracy of an indicator in measuring the construct attributed to it. The primary use of outer loading is to evaluate convergent validity, namely, the extent to which the indicators of a construct actually measure that construct. Based on the results of the analysis of the measurement model that has been conducted (Table 2), the results of the convergent validity test show very positive and convincing findings. This test evaluates whether each item used in this research questionnaire is truly capable of measuring the specified variable. The outer loading value is the main benchmark, where a number above 0.70 indicates that a question is a strong reflection of its variable (Hair *et al.*, 2011).

Table 2: Outer Loading

	(X1)	(X2)	(X3)	(X4)	(X5)	(X6)	(Y)	(Z1)	(Z2)
X1_1	0.858								
X1_2	0.930								
X1_3	0.896								
X1_4	0.915								
X1_5	0.930								
X2_1		0.847							

	(X1)	(X2)	(X3)	(X4)	(X5)	(X6)	(Y)	(Z1)	(Z2)
X2 2		0.920							
X2 3		0.867							
X2 4		0.872							
X2 5		0.855							
X3 1			0.901						
X3 2			0.878						
X3 3			0.819						
X3 4			0.862						
X3 5			0.869						
X4 1				0.894					
X4 2				0.938					
X4 3				0.932					
X4 4				0.898					
X4 5				0.896					
X5 1					0.923				
X5 2					0.862				
X5 3					0.931				
X5 4					0.901				
X5 5					0.908				
X6 1						0.867			
X6 2						0.888			
X6 3						0.908			
X6 4						0.899			
X6 5						0.916			
Y1 1							0.951		
Y1 2							0.963		
Y1 3							0.949		
Y1 4							0.960		
Y1 5							0.954		
Z1 1								0.959	
Z1 2								0.929	
Z1 3								0.930	
Z1 4								0.957	
Z1 5								0.950	
Z2 1									0.956
Z2 2									0.954
Z2 3									0.941
Z2 4									0.966

	(X1)	(X2)	(X3)	(X4)	(X5)	(X6)	(Y)	(Z1)	(Z2)
Z2 5									0.934

Note: X1: Technology, X2: Organization, X3: Regulation, X4: Supply Chain Risk, X5: Cost Perception, X6: Environmental Awareness, Z1: New Economy Investment (BEI), Z2: Livelihood Resilience (LR), Y: Sustainable Supply Chain Performance (SSCP).

The analysis results show that all independent variables in this study, namely variables X1, X2, X3, X4, X5, and X6, have highly valid indicators. The outer loading values for all indicators of variable X are consistently above 0.80, which far exceeds the minimum threshold. This confirms that respondents understood the questions asked and answered them consistently according to the construct being measured. In other words, the measurement tools for these six independent variables proved reliable and accurate. The strength of the measurement model is evident in the dependent variable (Y) and the mediating variables (Z1 and Z2). The indicators for these three variables demonstrate an extraordinarily high level of validity, with almost all outer loading values approaching perfect, namely above 0.90. This high value suggests that the questions designed to measure variables Y, Z1, and Z2 have a very close and strong relationship with the concepts they represent. This provides high confidence that these variables are measured with excellent precision.

Construct Validity and Reliability

Table 3 presents the results of the construct validity and reliability assessment. All constructs meet — and in most cases far exceed — the recommended thresholds for good measurement quality. This provides a strong basis for continuing further analysis, given the very high quality of the data and measuring instruments.

The convergent validity aspect, as measured by the Average Variance Extracted (AVE), shows that each construct is able to explain more than 50% of the variance of its indicators. All AVE values for each variable, from X1 (Technology) to Y (Sustainable Supply Chain Performance), are consistently well above the threshold of 0.50. For example, the Technology variable (X1) has an AVE of 0.821, meaning 82.1% of the variance of the Technology indicator can be explained by the Technology construct itself. Similarly, the Sustainable Supply Chain Performance variable (Y) achieves a very high AVE value of 0.913, indicating that its indicators are very strong in measuring the construct. The high AVE values for all constructs confirm that each set of indicators has excellent convergent validity, meaning that the indicators strongly and accurately measure the constructs they are supposed to. The structural model exhibits strong explanatory power. Blue Economy Investment shows a substantial R^2 of 0.866, indicating that the proposed antecedents account for most of its variance. Livelihood Resilience and Sustainable Supply Chain Performance also demonstrate high explanatory levels with R^2 values of 0.749 and 0.748, respectively. Predictive relevance is likewise robust. Blue Economy Investment achieves a Q^2 of 0.816, while Livelihood Resilience ($Q^2 = 0.699$) and Sustainable Supply Chain Performance ($Q^2 = 0.698$) also exceed the 0.50 threshold. These results confirm that the model possesses strong predictive accuracy across all endogenous constructs.

Table 3: Construct Validity and Reliability

<i>Construct</i>	<i>Cronbach's Alpha</i>	<i>rho_A</i>	<i>Composite Reliability</i>	<i>AVE</i>	<i>R²</i>	<i>Q²</i>
X1 (Technology)	0.946	0.950	0.958	0.821	—	—
X2 (Organization)	0.922	0.925	0.941	0.762	—	—
X3 (Regulation)	0.917	0.920	0.938	0.750	—	—
X4 (Supply Chain Risk)	0.949	0.951	0.961	0.831	—	—
X5 (Cost Perception)	0.945	0.956	0.958	0.819	—	—
X6 (Environmental Awareness)	0.938	0.944	0.953	0.802	—	—
Z1 (Blue Economy Investment)	0.970	0.971	0.977	0.893	0,866	0.816
Z2 (Livelihood Resilience)	0.973	0.973	0.979	0.903	0,749	0.699
Y (Sustainable Supply Chain Performance)	0.976	0.976	0.981	0.913	0,748	0.698

Note: X1: Technology, X2: Organization, X3: Regulation, X4: Supply Chain Risk, X5: Cost Perception, X6: Environmental Awareness, Z1: New Economy Investment (BEI), Z2: Livelihood Resilience (LR), Y: Sustainable Supply Chain Performance (SSCP).

Construct reliability testing, conducted using three key measures — Cronbach's Alpha, rho_A (Dijkstra-Henseler's rho), and Composite Reliability — also yielded very satisfactory results. The general criterion for good reliability is a value above 0.70. Cronbach's Alpha for all constructs showed values above 0.90, even reaching 0.976 for variable Y (Sustainable Supply Chain Performance). This indicates exceptionally high internal consistency across each set of indicators. rho_A also showed similar and very high values, above 0.90 for all constructs, confirming consistent reliability. Finally, Composite Reliability was also above 0.90 for all constructs, with some even approaching 0.98 (e.g., Y at 0.981 and Z1 at 0.977). These values far exceed the minimum threshold of 0.70, indicating that the measurements for each construct are highly consistent and stable. After ensuring convergent validity and construct reliability, the next important step is to evaluate discriminant validity. Discriminant validity aims to ensure that each construct in the model is uniquely distinct from the other constructs. In other words, we want to ensure that variables that are supposed to be distinct are truly separate and do not overlap. In this study, discriminant validity was tested using the Heterotrait-Monotrait Ratio (HTMT) (Table 4).

Table 4: Heterotrait-Monotrait Ratio (HTMT)

	(X1)	(X2)	(X3)	(X4)	(X5)	(X6)	(Y)	(Z1)	(Z2)
(X1)									
(X2)	0.326								
(X3)	0.268	0.365							
(X4)	0.263	0.349	0.369						

	(X1)	(X2)	(X3)	(X4)	(X5)	(X6)	(Y)	(Z1)	(Z2)
(X5)	0.251	0.359	0.324	0.272					
(X6)	0.307	0.360	0.275	0.261	0.298				
(Y)	0.552	0.620	0.645	0.541	0.533	0.571			
(Z1)	0.600	0.610	0.547	0.588	0.515	0.586	0.891		
(Z2)	0.540	0.589	0.665	0.550	0.496	0.589	0.904	0.788	

Note: X1: Technology, X2: Organization, X3: Regulation, X4: Supply Chain Risk, X5: Cost Perception, X6: Environmental Awareness, Z1: New Economy Investment (BEI), Z2: Livelihood Resilience (LR), Y: Sustainable Supply Chain Performance (SSCP).

Based on Table 4, the results of the HTMT test indicate that all constructs in the model have excellent discriminant validity. A common criterion for HTMT is a value below 0.90 (or some use a stricter threshold of 0.85). If the HTMT value is below this threshold, it indicates that each construct is unique and separate from the others. In detail, the relationships between the independent variables (X1 to X6) can be seen: All HTMT values for the X variables are very low, ranging from 0.251 to 0.369. These values are well below the threshold of 0.90 (and even 0.85). This indicates that the variables Technology (X1), Organization (X2), Regulation (X3), Supply Chain Risk (X4), Perceived Cost (X5), and Environmental Awareness (X6) are distinct constructs and do not significantly overlap.

The relationship between the independent variable (X) with the mediating variables (Z1 and Z2) and the dependent variable (Y): The HTMT values between variables X with Y, Z1, and Z2 also show very good results. For example, the HTMT between X1 (Technology) with Y (Sustainable Supply Chain Performance) is 0.552, and between X1 and Z1 (New Economic Investment) is 0.600. All of these values are still far below the threshold of 0.90. This confirms that the independent, mediating, and dependent variables effectively measure different concepts.

The relationship between the mediating variables (Z1 and Z2) and the dependent variable (Y): The relationship between Z1 (New Economic Investment) and Y (Sustainable Supply Chain Performance) has an HTMT value of 0.891. Similarly, the relationship between Z2 (Livelihood Resilience) and Y is 0.904. And between Z1 and Z2 is 0.788. Although the HTMT values between Z1 and Y, and Z2 and Y, are slightly higher than the other relationships, it should be noted that some of these values are still very close to, or slightly exceed, the 0.90 threshold. If using a threshold of 0.90, then the relationship of Z2 with Y (0.904) and Z1 with Y (0.891) still needs to be considered carefully. However, if using a looser threshold (for example, 0.95), then all relationships are still acceptable. Although one or two values approach the threshold, overall, the HTMT values for all pairs of constructs do not significantly exceed the 0.90 threshold. Thus, it can be concluded that each construct in this research model is empirically distinct and does not measure the same thing, so the requirements for discriminant validity have been met. The success of this HTMT test further strengthens confidence in the quality of the measurement model developed in this study.

Fit Models

Based on the model fit test results in Table 5, the SRMR values for both the saturated and estimated models were 0.042 and 0.043, respectively, lower than the threshold of 0.08 and even below 0.05. This indicates that the model fits the data well (Hair *et al.*, 2021). The d_ULS and d_G values were also relatively small, indicating that the difference between the model and the empirical data was insignificant and supporting the model's suitability (Henseler, Hubona and Ray, 2017). Meanwhile, the Chi-Square values were 1173.284 (saturated) and 1167.420 (estimated). In the context of PLS-SEM, this measure is only informative and is not used as the primary basis for model evaluation (Sarstedt, Ringle and Hair, 2021). Furthermore, the NFI value of 0.867–0.868 is still below 0.90, but has exceeded the minimum limit of 0.80, thus being categorized as an acceptable fit (Hair *et al.*, 2021). Overall, the model is fit for further analysis in further analysis, both at the evaluation stage of the measurement model (outer model) and the structural model (inner model).

Table 5: Fit Model

Size Fit Models	Saturated Model	Estimated Model	Acceptance Criteria	Interpretasi
SRMR	0.042	0.043	<0.08 = good fit; <0.05 = excellent fit (Hair <i>et al.</i> , 2021)	A value <0.05 indicates a very good fit for the model.
d_ULS	1.859	1.945	No absolute cut-off; compared with bootstrapping results (Hair <i>et al.</i> , 2021)	A relatively small value indicates the model closely approximates the empirical data.
d_G	1.481	1.495	No absolute cut-off; compared with bootstrapping results (Henseler <i>et al.</i> , 2020)	A relatively small value supports the model's suitability.
Chi-Square	1173.284	1167.42	Additional information: not a primary measure in PLS-SEM (Sarstedt <i>et al.</i> , 2022)	This is purely descriptive and is not the primary basis for model acceptance in PLS.
NFI	0.867	0.868	>0.90 = good; >0.80 = acceptable (Hair <i>et al.</i> , 2021)	This value falls within the acceptable fit category, although not optimal.

Hypothesis Testing

The test results show that all 14 hypotheses proposed in this study are accepted, indicating a significant relationship between the variables according to the proposed model (Figure 4 and Table 6).

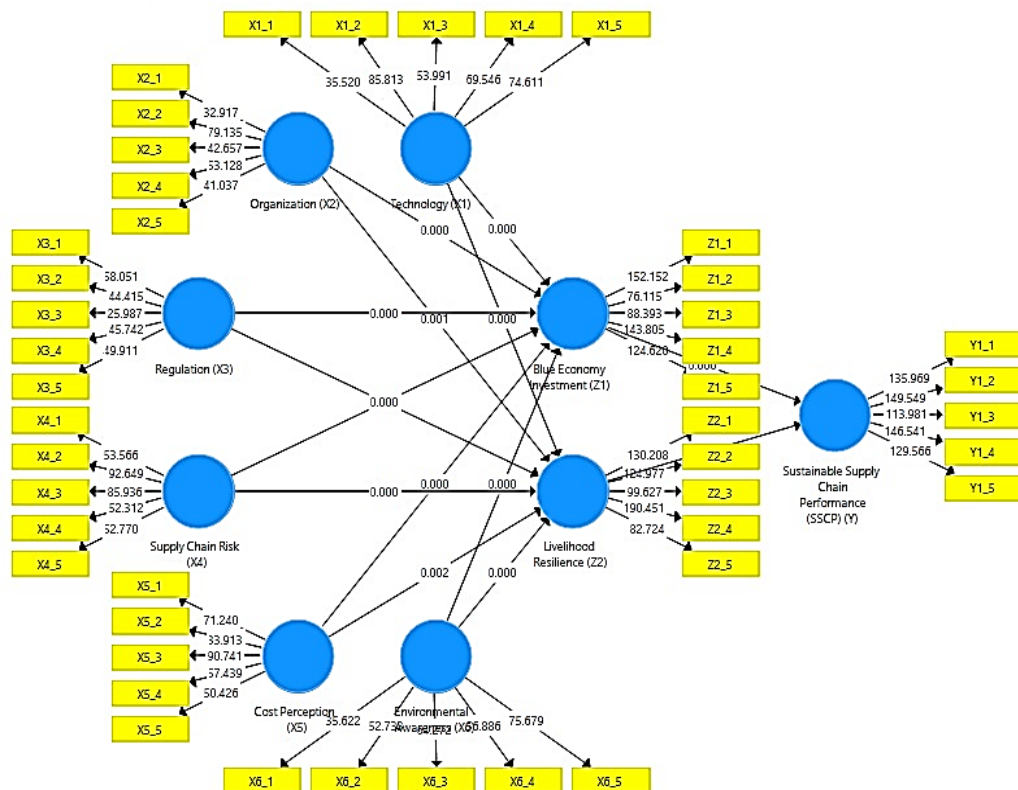


Figure 4: Model Algorithm Results

Table 6: Hypothesis Testing

	<i>Original Sample (O)</i>	<i>Sample Mean (M)</i>	<i>Standard Deviation</i>	<i>T Statistics</i>	<i>P Values</i>	<i>Hypothesis Testing</i>
(X1) -> (Z1)	0.293	0.293	0.047	6.227	0.000	Accepted
(X1) -> (Z2)	0.222	0.222	0.050	4.404	0.000	Accepted
(X2) -> (Z1)	0.205	0.205	0.051	4.050	0.000	Accepted
(X2) -> (Z2)	0.179	0.176	0.052	3.458	0.001	Accepted
(X3) -> (Z1)	0.169	0.169	0.046	3.707	0.000	Accepted
(X3) -> (Z2)	0.335	0.337	0.045	7.494	0.000	Accepted
(X4) -> (Z1)	0.259	0.257	0.042	6.124	0.000	Accepted
(X4) -> (Z2)	0.195	0.192	0.043	4.570	0.000	Accepted
(X5) -> (Z1)	0.166	0.168	0.046	3.577	0.000	Accepted

	<i>Original Sample (O)</i>	<i>Sample Mean (M)</i>	<i>Standard Deviation</i>	<i>T Statistics</i>	<i>P Values</i>	<i>Hypothesis Testing</i>
(X5) -> (Z2)	0.141	0.142	0.050	2.837	0.005	Accepted
(X6) -> (Z1)	0.254	0.251	0.046	5.504	0.000	Accepted
(X6) -> (Z2)	0.264	0.262	0.049	5.394	0.000	Accepted
(Z1) -> (Y)	0.465	0.467	0.051	9.080	0.000	Accepted
(Z2) -> (Y)	0.524	0.523	0.051	10.349	0.000	Accepted

Note: X1: Technology, X2: Organization, X3: Regulation, X4: Supply Chain Risk, X5: Cost Perception, X6: Environmental Awareness, Z1: New Economy Investment (BEI), Z2: Livelihood Resilience (LR), Y: Sustainable Supply Chain Performance (SSCP)

Relationship of Independent Variables (X) with Mediating Variables (Z1 and Z2): All independent variables, namely Technology (X1), Organization (X2), Regulation (X3), Supply Chain Risk (X4), Perceived Cost (X5), and Environmental Awareness (X6), were shown to have a positive and significant influence on the two mediating variables, namely New Economic Investment (Z1) and Livelihood Resilience (Z2). The P values for all these paths were 0.000 or 0.001, which is significantly less than 0.05. For example, Technology (X1) had a significant influence on New Economic Investment (Z1) with a path coefficient of 0.293 (P = 0.000) and on Livelihood Resilience (Z2) with a path coefficient of 0.222 (P = 0.000). Similarly, the Regulation variable (X3) shows a strong influence on Livelihood Resilience (Z2) with a path coefficient of 0.335 (P Values = 0.000), indicating that increased regulation contributes to increased livelihood resilience.

The Relationship of Mediating Variables (Z1 and Z2) to the Dependent Variable (Y): The New Economic Investment (Z1) and Livelihood Resilience (Z2) variables are also proven to have a positive and highly significant influence on Sustainable Supply Chain Performance (Y). New Economic Investment (Z1) has a positive influence on Sustainable Supply Chain Performance (Y) with a path coefficient of 0.465 and P P-value of 0.000. Meanwhile, Livelihood Resilience (Z2) shows an even stronger influence on Sustainable Supply Chain Performance (Y) with a path coefficient of 0.524 and P Values of 0.000. This confirms the central role of these mediating variables in driving Sustainable Supply Chain Performance.

Hypothesis testing results indicate that all relationships are statistically significant. This outcome aligns with theoretical expectations in the sustainability and fisheries supply chain literature. Technological adoption (X1) and organizational capacity (X2) consistently enhance investment behavior and resilience because improved operational systems, digital tools, and institutional support reduce uncertainty and encourage long-term economic planning (Anand *et al.*, 2024; Brugere, Onuigbo and Morgan, 2017). Regulatory enforcement (X3) also shows strong effects, particularly on livelihood resilience, as clear governance structures, licensing certainty, and resource-use regulations increase compliance and support adaptive behavior among coastal communities. Supply chain risk (X4) and cost perception (X5) significantly influence blue economy investment and resilience, which is theoretically consistent with risk

management and behavioral economics frameworks. Households facing manageable risks and favorable cost structures are more willing to allocate capital toward sustainable marine-based ventures. Environmental awareness (X6) also demonstrates substantial effects, consistent with ecological modernization theory, wherein actors with higher environmental literacy tend to invest more responsibly and adopt sustainable practices (Efani *et al.*, 2024a). Furthermore, both blue economy investment (Z1) and livelihood resilience (Z2) significantly improve sustainable supply chain performance (Y). This supports value chain and resilience theories, which posit that financial capacity, diversification of income sources, and adaptive capabilities strengthen the efficiency, sustainability, and competitiveness of fisheries supply chains.

Discussion

The findings reveal that technology (X1) plays a transformative role in modernizing small-scale fisheries by simultaneously increasing productivity, reducing inefficiencies, and expanding economic opportunities. Innovations such as echo-sounder-equipped Fish Aggregating Devices (FADs) have notably improved tuna catch efficiency, while investments in cold chain infrastructure and processing technologies have reduced post-harvest losses and enhanced product quality (Tidd *et al.*, 2023). Digitalization through mobile platforms, IoT tools, and online marketplaces streamlines market access by reducing dependence on intermediaries and linking fishers directly with buyers (Hungevu *et al.*, 2025). Fintech platforms also lower capital constraints by improving access to credit and digital payments, enabling small-scale actors to reinvest in both technology and human capabilities (Sharma *et al.*, 2025). Collectively, these technological innovations demonstrate that technology-driven investment is not merely an operational enhancement but a foundational driver of resilient and competitive Blue Economy supply chains. These findings are empirically supported by the significant positive effects of technology on both Blue Economy Investment ($X1 \rightarrow Z1 = 0.293$, $p < 0.001$) and Livelihood Resilience ($X1 \rightarrow Z2 = 0.222$, $p < 0.001$), as shown in Table 6, confirming that technological readiness directly amplifies investment behavior and adaptive capacity.

Beyond technological solutions, the role of collective organization (X2) is critical for overcoming structural constraints faced by small-scale fishers. Individually, most lack sufficient collateral, financial literacy, or bargaining power, but cooperatives or Joint Business Groups (JBGs) help pool resources and create economies of scale that unlock opportunities for larger and more strategic investments (Fisher and Neubert, 2023). By shifting the perception of fishers from high-risk individuals to organized economic entities, JBGs also increase bankability and improve access to formal financial systems (Gu, 2025). In parallel, these organizations function as safety nets, managing internal savings and loan schemes and facilitating access to insurance products. They also build social capital, fostering trust and reciprocity among members, which strengthens resilience during times of crisis (Putra *et al.*, 2021; Sorensen *et al.*, 2022). This aligns directly with the statistical results showing significant pathways from organization to investment ($X2 \rightarrow Z1 = 0.205$, $p < 0.001$) and to livelihood resilience ($X2 \rightarrow Z2 = 0.179$, $p = 0.001$), reinforcing that stronger collective structures translate into higher investment readiness and adaptive capacity.

The institutional benefits of collective organization extend further into policy engagement and advocacy. As intermediaries, cooperatives bridge the gap between government agencies and small-scale fishers, ensuring that development programs such as training, equipment provision, and subsidies are effectively channeled to communities (Efani *et al.*, 2024b; Enema and Quezon, 2024). They amplify collective voices, allowing fishers to engage in decision-making processes and influence regulatory frameworks that shape their livelihoods. In this context, organization strengthens both economic outcomes and social inclusion, which are essential dimensions of long-term resilience (Richmond and Casali, 2022).

The regulatory and policy landscape (X3) shapes the extent to which technology and collective action can succeed. Supportive and predictable regulations are critical for attracting investment, creating legal certainty, and incentivizing sustainable practices. For instance, policies that formalize tenure rights encourage fishers to adopt resource-conserving technologies with the confidence that future benefits will be secured (Domguia *et al.*, 2023). At the same time, policies that subsidize environmentally friendly equipment or processing facilities can stimulate pro-sustainability investment, while poorly designed subsidies, such as fuel support, often perpetuate overfishing and erode resilience (Sowman and Sunde, 2018). Equally important, regulatory frameworks provide the institutional infrastructure for resilience by protecting marine resources and supporting social safety nets. Well-managed Marine Protected Areas (MPAs) can restore fish stocks, creating spillover benefits that stabilize catches and ensure long-term supply chain continuity. In addition, Fisher insurance schemes, disaster relief funds, and targeted welfare programs help households buffer against shocks, reducing their vulnerability to economic and environmental risks (Efani *et al.*, 2024c). Nevertheless, policies imposed in a top-down manner without community engagement risk undermining livelihoods and exacerbating social tensions (Vervoort *et al.*, 2024). Thus, participatory and inclusive governance becomes indispensable. The strong empirical effects of regulation on both investment ($X3 \rightarrow Z1 = 0.169$, $p < 0.001$) and resilience ($X3 \rightarrow Z2 = 0.335$, $p < 0.001$) confirm that regulatory clarity and institutional support are foundational enablers of sustainable development pathways.

Supply chain risk navigation (X4) demonstrates that risk perception often functions as a catalyst for investment rather than a deterrent. Awareness of post-harvest losses can encourage investment in cold storage facilities, while exposure to price volatility motivates fishers to pursue product diversification and enter more stable value-added markets (Garton, Thow and Swinburn, 2021; Ali, Farow and Mohamud, 2025). Similarly, climate-related risks have stimulated adaptation strategies, including investments in aquaculture and alternative income-generating activities. This indicates that proactive risk management transforms uncertainty into an opportunity for resilience-building. Moreover, collective and relational strategies for risk-sharing reinforce resilience at both community and supply chain levels. Diversification of species, markets, and income streams spreads vulnerability across different sectors, while collaborative arrangements — such as long-term contracts or joint marketing — reduce exposure to volatility (Birchenough, 2023; N'Souvi *et al.*, 2024). In this way, investments in risk management safeguard not only the stability of supply chain operations but also the security of fishing households. This interpretation is supported by the significant path coefficients from supply chain risk to investment ($X4 \rightarrow Z1 =$

0.259, $p < 0.001$) and to resilience ($X4 \rightarrow Z2 = 0.195$, $p < 0.001$), indicating that risk awareness stimulates adaptive strategies rather than discouraging action.

Institutional collaboration (X5) further strengthens the adaptive capacity of the Blue Economy by mobilizing resources and aligning incentives across multiple actors. Government agencies can provide infrastructure, NGOs facilitate capacity building, research institutions deliver innovation, and the private sector opens access to markets (Tikadar *et al.*, 2022). Co-management arrangements, where communities share responsibility with formal authorities, enhance compliance, build trust, and improve stewardship of marine resources. These forms of collaboration reduce transaction costs, accelerate innovation, and create a governance environment conducive to both investment and resilience. This corresponds with the significant but smaller positive impacts of institutional collaboration on investment ($X5 \rightarrow Z1 = 0.166$, $p < 0.001$) and on resilience ($X5 \rightarrow Z2 = 0.141$, $p = 0.005$), showing that collaborative arrangements complement but do not replace the structural roles of technology, regulation, and organization.

Public-private partnerships add another dimension of institutional collaboration, particularly in accessing premium markets. Certification schemes for sustainable fisheries, for example, require cooperation among regulators, producer groups, and certifying bodies. Such initiatives not only provide market incentives for sustainable practices but also embed resilience within supply chains by aligning ecological goals with economic opportunities. By pooling knowledge, authority, and resources, institutional collaboration creates systemic resilience that individual actors alone could not achieve. Environmental awareness (X6) functions as both a normative driver and a practical necessity for sustainable development in the Blue Economy. Increasing recognition of ecological limits has pressured stakeholders to adopt environmentally responsible practices, from reducing destructive fishing methods to restoring coastal habitats. Investments in sustainable technologies and ecosystem restoration align with broader global agendas, such as the Sustainable Development Goals, while simultaneously enhancing long-term resource availability and ecological resilience. This growing environmental consciousness ensures that economic gains do not come at the expense of future generations but rather support inclusive, sustainable growth. Together, these six factors—technology, collective organization, regulation, risk navigation, institutional collaboration, and environmental awareness—constitute an interdependent framework for inclusive Blue Economy development. Each factor contributes uniquely to investment dynamics, supply chain performance, and livelihood resilience, but their greatest strength lies in their synergy. When integrated, they not only address immediate constraints faced by small-scale fishers but also build adaptive capacity, ensuring that the Blue Economy becomes a sustainable pathway for both economic growth and social equity. The SEM results show strong and consistent pathways from environmental awareness to investment ($X6 \rightarrow Z1 = 0.254$, $p < 0.001$) and to resilience ($X6 \rightarrow Z2 = 0.264$, $p < 0.001$), confirming that ecological consciousness directly shapes decision-making and long-term adaptive behavior.

From a theoretical perspective, the integration of these six factors resonates strongly with both the TOE and NRBV frameworks. Within the TOE framework, technology (X1), organizational capacity (X2), and environmental or regulatory contexts (X3, X5, X6)

jointly determine the adoption and diffusion of innovation, highlighting how systemic readiness shapes investment decisions and performance outcomes. The NRBV framework, meanwhile, emphasizes the strategic value of rare, valuable, inimitable, and non-substitutable resources, where natural capital and ecological stewardship become sources of sustained competitive advantage. Risk navigation (X4) and environmental awareness (X6) exemplify how firms and communities not only mitigate vulnerabilities but also transform ecological and social challenges into long-term opportunities. When viewed together, TOE explains the conditions that enable innovation, while NRBV explains why aligning investments with ecological sustainability creates enduring resilience and competitiveness. Thus, the integrated TOE–NRBV perspective provides a robust analytical lens to understand how supply chain performance (Z1) and livelihood resilience (Z2) can be simultaneously achieved in inclusive Blue Economy development.

Conclusion

This study shows that inclusive Blue Economy development in southern coastal Malang requires the simultaneous strengthening of sustainable supply chain performance and the livelihood resilience of small-scale fishers. Empirical results demonstrate that technological innovation, collective organization, supportive regulations, risk navigation, cost perception, and environmental awareness all significantly influence both Blue Economy investment and resilience outcomes. Among these, livelihood resilience exerts the greatest impact on supply chain sustainability, underscoring the importance of empowering fishing households through diversification, social networks, and adaptive capacity. The integrated TOE–NRBV framework developed here bridges the gap between macro-policy objectives and micro-level realities, offering a comprehensive pathway for coastal development that balances economic growth, social equity, and ecological stewardship. Policy implications highlight the importance of participatory governance, targeted investments, and digital transformation strategies to ensure that small-scale fisheries become resilient and competitive actors in the global Blue Economy.

The findings carry clear policy implications. Strengthening participatory governance is essential to ensure that regulations reflect local needs and enhance resource stewardship. Targeted investments in digital technologies, cold chain systems, and sustainable fishing equipment can improve supply chain efficiency and reduce vulnerability. Equally important are institutional arrangements — such as cooperatives, co-management structures, and public–private partnerships — that empower small-scale fishers as active economic actors rather than passive beneficiaries. By aligning technological, economic, institutional, and ecological priorities, policymakers and stakeholders can support a Blue Economy model in which small-scale fisheries become resilient, sustainable, and competitive contributors to regional development.

The study is limited by its geographic focus on the southern coastal region of Malang, which may restrict the generalizability of findings to other socio-ecological contexts. The use of self-reported survey data also introduces the potential for response bias, particularly in variables related to perceptions and adaptive behaviors. Future research could include multi-regional comparative studies to validate the TOE–NRBV model across different fisheries systems, as well as incorporate longitudinal or mixed-method

designs to capture dynamic changes in resilience, investment behavior, and supply chain performance over time.

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Appendix C

KEY INFORMANT INTERVIEWS GUIDE

A. Sustainable Energy Strategies

1. What kind of after-sales technical support or maintenance services does SES provide to rural users and how accessible are these services in Kiambu County?
2. Are there trained local technicians or agents in rural areas who can assist with biogas installation and repairs? If not what is being done to build that capacity?
3. Installation cost has been reported as a major barrier. Does SES offer any financing plans, subsidies or partnerships to make systems more affordable for low-income households?
4. What efforts are made to educate users on alternative feedstock options?
5. Has SES considered user feedback in the design of its systems for rural households?
6. Does SES work with local governments, NGOs or CBOs in promoting and supporting biogas adoption? If so how?
7. How does SES monitor the usage and performance of its systems after installation, particularly in rural settings?
8. Are there any policies and regulations with regard to piping of biogas?
9. Does your organization offer any kind of incentive to your customers to encourage increased biogas uptake?
10. What are SES plans to scale up adoption in rural counties like Kiambu, and how do you plan to overcome barriers?

B. New Josman Juakali Agencies

1. Tell me about your experience in jiko fabrication- how long have you been doing this?
2. What types of jikos do you specialise in, and who are your typical clients?
3. What materials do you commonly use and where do you source them?
4. What design features make your improved jikos more efficient than traditional ones?
5. Do you modify jiko designs based on customer's feedback or specific needs?
6. What are the most common reasons customers give for wanting improved jikos?
7. What type or size of jikos are most in demand?
8. How do cost and affordability affect the uptake of improved jikos among institutions?
9. Do you offer any payment plans or work with NGOs or government programs to reach more clients?
10. What are the biggest challenges you face as a fabricator? (material cost, competition, regulation)
11. Have you faced any challenge with customer satisfaction or product performance?
12. Do you receive any support? (Technical training, access to finance, tools, from government or NGOs?)
13. How familiar are you with clean cooking initiatives or policies in Kenya
14. What do you think needs to be done to improve adoption of cleaner cooking technologies?
15. What support do you think artisans like yourself need to scale up and improve clean cooking access in rural areas?

Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

<i>Contribution</i>	<i>Author 1</i>	<i>Author 2</i>	<i>Author 3</i>	<i>Author 4</i>	<i>Author 5</i>
Conceived and designed the research or analysis	Yes	No	Yes	Yes	No
Collected the data	Yes	No	Yes	No	No
Contributed to data analysis & interpretation	Yes	Yes	No	Yes	No
Wrote the article/paper	Yes	Yes	No	No	No
Critical revision of the article/paper	No	Yes	No	Yes	No
Editing of the article/paper	No	Yes	No	Yes	Yes
Supervision	No	Yes	Yes	No	Yes
Project Administration	Yes	No	Yes	No	No
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Overall Contribution Proportion (%)	40	25	15	15	5

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Research involving human bodies or organs or tissues (Helsinki Declaration)

The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

Research involving animals (ARRIVE Checklist)

The author(s) solemnly declare(s) that this research has not involved any animal subject (body or organs) for experimentation. The research was not based on laboratory experiment involving any kind animal. The contexts of animals were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of ARRIVE does not apply in cases of this study or written work.

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The author(s) solemnly declare(s) that this research has not involved Indigenous Peoples as participants or respondents. The contexts of Indigenous Peoples or Indigenous Knowledge were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or prior informed consent (PIC) of the respondents or Self-Declaration in this regard does not apply in cases of this study or written work.

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Research Involving Local Community Participants (Non-Indigenous) or Children

The author(s) solemnly declare(s) that this research has not directly involved any local community participants or respondents belonging to non-Indigenous peoples. Neither this study involved any child in any form directly. The contexts of different humans, people, populations, men/women/children and ethnic people were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or prior informed consent (PIC) of the respondents or Self-Declaration in this regard does not apply in cases of this study or written work.

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